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High-Precision Estimation of the Time of Arrival of Radio Signals

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Abstract—An interpolation algorithm of high-precision estimation of the time of arrival of radio signals has been proposed. Analytical expressions were obtained for specifications of the algorithm that were corroborated by the results of computer simulation. It was shown that with due regard for the complexity adequate to a receiver of the maximum likelihood estimation of the temporal position with quantized output, the proposed interpolation algorithm ensures the noise immunity close to potentially attainable. The performed analysis makes it possible to select parameters of the estimation algorithm in a reasonable way depending on the requirements to its accuracy and complexity of realization.

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System of time synchronization is an integral part of state-of-the-art wideband (WB) systems of communications, radio navigation, and other technical fields. The main problem in creating such systems is the development of an efficient algorithm for estimating the temporal position of the WB signal received.

Navigation systems based on distance-measuring or difference distance-measuring techniques of positioning have received wide recognition. These techniques were used as a basis for building satellite navigation systems using the GPS and GLONASS technologies, and also systems of locating mobile subscribers in cellular CDMA or WCDMA networks [1]. In addition, the distance-measuring technique can be successfully used for determining the coordinates of sources of emergency calls for the medical and technical aid in the urban conditions or in large industrial areas. The efficient operation of such systems implies the need of an algorithm for high-precision determination of the time of arrival of the signal used.

Temporal position of the signal is determined by the output signal of optimal filter. Signal with the chip structure is often used as a legitimate signal in the specified systems. Under the circumstances, for navigation tasks the estimation error should not exceed a small fraction of the chip (duration of an elementary symbol of the pseudorandom sequence). In this case, the use of conventional estimation of the temporal position by the maximum value of the output signal involves the need of generating this output signal with a very small time discrete resulting in considerable technical and computational expenses.

The purpose of this study was to develop and analyze a simple high-accuracy algorithm for estimating the temporal position of radio signal.

Let the additive mixture of the legitimate signal and noise be observed at a certain interval of the analysis

$$x(t) = s(t,\tau_0,A_0,\psi_0) + n(t), \tag{1}$$

where $n(t)$ is white Gaussian noise with one-sided spectral density N_0, $\langle n(t_1)n(t_2)\rangle = (N_0/2)\delta(t_1 - t_2)$, $\delta(\cdot)$ is delta function,

$$s(t,\tau,A,\psi) = A\,g(t-\tau)\cos(w_0 t - \psi) \tag{2}$$

where $s(t, \tau, A, \psi)$ is a legitimate quasideterministic signal having duration T; A, ψ are a priori unknown signal amplitude and phase that are approximately constant at the interval of signal duration; w_0 is the carrier angular frequency; $g(t)$ is a priori known function determined generally by the pseudorandom sequence (PRS) used and the filter limiting the signal frequency band; τ is an unknown temporal position of the signal from a priori interval $[0, \tau_{max}]$. Index "0" in expression (1) denotes the true value of unknown parameters. This model provides a good description of the pilot signal or preamble utilized for time synchronization in